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Money does not stink: Using unpleasant odors as stimulus material changes risky decision making

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Abstract
Odors are strong elicitors of affect, and they play an important role in guiding human behavior, such as avoiding fire or spoiled food. However, little is known about how risky decision making changes when stimuli are olfactory. We investigated this question in an experimental study of risky decision making with unpleasant odors and monetary losses in a fully incentivized task with real outcomes. Odor and monetary decisions were matched so that monetary losses corresponded to the amount of money participants were willing to pay to avoid smelling an odor. Hierarchical Bayesian analyses using prospect theory show that participants were less sensitive to probabilities when gambling with odors than when gambling with money. These results highlight the importance of taking the sensory modality into account when studying risky decision making.

KEYWORDS
affect, odors, probability weighting, prospect theory, risky decision making

1 | INTRODUCTION

Olfaction is a fundamental sense that plays an important role in guiding behavior in humans and other animals, for instance, by signaling when food might be dangerous to ingest or when there is a nearby environmental hazard, such as fire (Stevenson, 2009). In this vein, odors have been shown to play an important part in decision processes, including food choice (e.g., Demattè, Endrizzi, & Gasperi, 2014; Gaillet-Torrent, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2014) and selecting a partner (e.g., Ferdenzi, Delplanque, Atanassova, & Sander, 2016; Herz & Cahill, 1997). Furthermore, odors strongly affect cognitive, affective, and physiological processes (e.g., Coppin, Parma, & Pause, 2016; Herz, Eliassen, Beland, & Souza, 2004; Mohanty & Gottfried, 2013) that, in turn, also influence decision processes. However, so far, olfactory stimuli play a surprisingly small role in research on decision making compared with visual or even auditory materials (e.g., Oud & Coppin, 2012), even though the required technology to study olfaction is readily accessible to researchers (e.g., Ischer et al., 2014; Sharvit, Dell'Acqua, & Vuilleumier, 2018). The goal of the present research was to gain a better understanding of how olfactory stimuli shape decision processes. Specifically, we investigated how the affective nature of odors changes the processes underlying risky choice using a computational modeling approach.

1.1 | Risky decision making and odors

Decision making under risk refers to choices between options that differ in the attractiveness or valence of their outcomes and the probability with which these outcomes occur. A typical example is the decision to buy insurance. Buying insurance entails a small but certain loss—the payment of a premium—whereas not buying insurance can result in either no loss or a major loss depending on whether the event covered by the insurance occurs. To study how people make decisions under risk, past studies often used lotteries with monetary gains or losses (e.g., Kahneman & Tversky, 2000; McGraw, Shafir, & Todorov, 2010). Outcomes of risky decision problems, however, are not strictly monetary but often involve nonmonetary outcomes, as when one must decide between different treatment options for a medical problem or choose between different career opportunities.

Although there is a large literature on the influence of odors on consumer behavior (for reviews see, Bradford & Desrochers, 2009; Rimkute, Moraes, & Ferreira, 2016), so far, only a few studies have investigated how odors influence decision making under risk (Ditto, Pizarro, Epstein, Jacobson, & Macdonald, 2006; Festjens, Bruyneel, & Dewitte, 2018; Hirsch, 1995; Kechagia & Drichoutis, 2017; Stancak et al., 2015). Specifically, Hirsch conducted a field experiment on the casino floor of a Las Vegas hotel. He scented two slot machine areas with two distinctive but pleasant odorants,[1] whereas a third area was left unscented. The amount of gambling in one of the scented areas increased significantly compared with the amount of gambling in the same area before and after the experimental manipulation, whereas the amount of gambling in the other scented area and the control area did not change. Hirsch proposed that the effect was mediated by a mood change induced by the odor. In contrast, Kechagia and Drichoutis (2017)) more recently did not find an effect of a pleasant ambient odor on risk preferences in a lottery task using a citrus scent. Finally, Stancak et al. (2015) found an increase in loss aversion while smelling an unpleasant odor (methyl mercaptan) but not a decrease in loss aversion while smelling a pleasant odor (jasmine). These studies suggest that odors may influence decisions under risk; however, in particular in regard to pleasant odors, the results are inconsistent. Furthermore, these studies all focused on the influence of "incidental" odors, that is, odors that were part of the context in which a decision took place but independent of the actual outcomes in the decision-making task. Yet, in many situations, odors are an integral feature of the decision option itself, such as in food or mate choice, where odors have been shown to play an important role in guiding choices (e.g., Ferdenzi et al., 2016; Regenbogen et al., 2017).

To our knowledge, there are only two studies that systematically investigated how olfactory stimulus material affects decision making under risk, that is, how decision makers choose among different odors or stimulus material with an olfactory component (Ditto et al., 2006; Festjens et al., 2018). Ditto et al. (2006) found in a risky decision task with cookies that participants who received only a description of the cookies they could win were more likely to accept the gamble when the probability of winning was high than when it was low. In contrast, participants who could see and smell the (freshly baked) cookies were equally likely to accept the gamble independent of the probability of winning the cookies. This result indicates that the olfactory cue (i.e., cookie scent) contributed to the changes in the decision process, suggesting that participants were less sensitive to probabilities when they were able to smell the cookies. In addition, the authors found that smelling the cookies increased participants' desire to win (i.e., the subjective value) and their perceived odds of winning, which both could have influenced their willingness to take risks. A mediation analysis testing whether perceived odds of winning or the perceived desirability of the cookies could explain the choice effects did not show any significant results. Furthermore, Festjens et al. (2018) failed to replicate the results reported by Ditto et al. In sum, to date, there is little research investigating the role of olfactory stimuli in risky decision making, and the results so far are ambiguous.

1.2 | Risky decision making with affect-rich and affect-poor stimulus material

Although little research has investigated how odors change the decision process, a relatively large number of studies have examined how risky decision making changes when outcomes are affect rich (i.e., elicit strong affective responses) compared with affect poor (i.e., elicit only weak or no affective responses; e.g., Hsee & Rottenstreich, 2004; Lejarraga, Pachur, Frey, & Hertwig, 2016; Pachur, Hertwig, & Wolkewitz, 2014; Pachur, Suter, & Hertwig, 2017; Petrova, Van der Pligt, & Garcia-Retamero, 2014; Rottenstreich & Hsee, 2001; Sunstein & Zeckhauser, 2011; Suter, Pachur, & Hertwig, 2016). Given the salient hedonic dimension of odors (e.g., Mohanty & Gottfried, 2013; for an overview, see O'Doherty, 2007), these studies seem highly relevant when exploring how olfactory stimuli can change risky decision making.

In a seminal paper, Rottenstreich and Hsee (2001; Study 3) compared how much participants were willing to pay to avoid gambles that resulted in either a loss of 20 USD or a mild electric shock with either a 1% or 99% chance. Participants were willing to pay a median amount of 18 USD to avoid a gamble with a 99% probability of losing 20 USD, but only 1 USD if the probability of the loss was just 1%. When the outcome was an electric shock, however, the median willingness to pay for the gambles was 10 USD and 7 USD for the 99% and 1% gamble, respectively. The authors argued that with affect-rich outcomes, people differentiate between certain and probabilistic outcomes but are insensitive to intermediate probability variations. Subsequently, a number of studies have shown a similar reduction in sensitivity to probabilities in risky choices with affect-rich outcomes using negative outcomes, such as medical side effects, and positive outcomes, such as holiday vouchers (e.g., Hsee & Rottenstreich, 2004; Pachur et al., 2014; Suter et al., 2016; but see Klein et al., 2018, for a failed attempt to replicate Rottenstreich & Hsee's, 2001, Study 1). The results also hold when values of the nonmonetary and monetary outcomes were carefully matched for each participant and when probabilities were provided or learned through experience (e.g., Lejarraga et al., 2016).

To understand the changes in the decision process better, Pachur et al. (2014, 2017) and Suter et al. (2016) modeled participants' choices with cumulative prospect theory (CPT; Tversky & Kahneman, 1992). CPT assumes that people's choices between risky options can be described by an expectation-based calculus that multiplies the subjective value of the outcomes by the subjective probabilities. CPT

[1]Unfortunately, the components of the fragrances used by Hirsch were not published.

captures how the objective outcomes and probabilities are perceived on a subjective level using two functions, the value function and the probability weighting function. For monetary gambles, the probability weighting function usually takes the form of an inverse-S shape, indicating that in the decision process, people tend to place more weight on small probabilities and less on large probabilities (e.g., Abdellaoui, 2000; Tversky & Kahneman, 1992). Pachur et al. (2017) showed that with affect-rich outcomes, the probability weighting function became more strongly curved, meaning that test subjects differentiated less between low and high probabilities. This supports the idea that insensitivity to differences in probabilities underlies the changes observed with affect-rich nonmonetary outcomes as compared with monetary outcomes.

1.3 | Risky decision making with real nonmonetary outcomes

Given the strong affective dimensions of odors, it seems likely that outcomes with an olfactory dimension should lead to a similar change in the sensitivity to probabilities in risky gambles. However, the large majority of studies on the influence of affect-rich outcomes on risky decision making have been conducted with hypothetical outcomes, and to date, only a handful have investigated risky decision making and probability weighting with real, nonmonetary outcomes (including the two studies using outcomes with an olfactory dimension reported above). These studies, which we review below, present a more ambiguous picture.

Specifically, four studies reported comparable findings with those of studies with hypothetical outcomes (Abdellaoui & Kemel, 2014; Ditto et al., 2006; Rosati & Hare, 2016; Sunstein & Zeckhauser, 2011). The study by Abdellaoui and Kemel (2014) used time as a nonmonetary outcome, the studies by Rosati and Hare (2016) and Ditto et al. (2006) food, and the study by Sunstein and Zeckhauser (2011) electric shocks. Two studies had a monetary control group (Abdellaoui & Kemel, 2014; Rosati & Hare, 2016), one a nonmonetary but likely affect-poor outcome (Ditto et al., 2006), and one study did not include a control group (Sunstein & Zeckhauser, 2011).

One study reported results pointing in the opposite direction (Krawczyk, 2015). Krawczyk compared probability weighting in decisions with real monetary and nonmonetary outcomes (vouchers) that differed in their stakes (i.e., value of vouchers and monetary gains could be high or low) and the affect richness of the vouchers (high or low). The affect elicited by the vouchers was manipulated by selecting affect-poor vouchers (for a local discount supermarket) and affect-rich vouchers (for a leisure and recreation company), where affect richness was established in a pretest. If the stakes were low, the outcome type did not affect probability weighting. If the stakes were high, participants underweighted probabilities when gambling with vouchers. However, the difference from monetary outcomes was largest for the affect-poor vouchers, which is in contrast to the idea that the differences in affect caused a diminished sensitivity to probabilities.

Two studies reported null effects, one by Festjens et al. (2018) attempting to replicate the study by Ditto et al. (2006) and one by Hayden and Platt (2009) comparing risky choices with juice and money. Last, a set of two studies measuring probability weighting in a risky decision-making task using real electric shocks as outcomes found nonlinear probability weighting functions that corresponded to the inverse-S-shaped function frequently reported for monetary gambles (Berns, Capra, Chappelow, Moore, & Noussair, 2008; Berns, Capra, Moore, & Noussair, 2007). The studies did not contain a control group with monetary losses, but the estimated probability curvature parameters from CPT corresponded closely to the values reported in the literature on risky decision making with monetary gambles (Abdellaoui, 2000; Berns et al., 2007; Tversky & Kahneman, 1992). This suggests no change in probability weighting when using presumably affect-rich electric shocks.

2 | PRESENT STUDY

In sum, to our knowledge, only two studies have investigated how risky decision processes change when the outcomes themselves have an olfactory component, and their results are inconsistent (Ditto et al., 2006; Festjens et al., 2018). Research on risky decision making with nonolfactory affect-rich outcomes suggests systematic changes in probability weighting, but these studies largely relied on hypothetical scenarios. The few studies that have used real nonmonetary outcomes reported somewhat inconsistent results and are difficult to compare due to methodological differences. In the present study, we investigated how the processes of risky decision making change when using olfactory stimuli as outcomes compared with monetary outcomes. We use a within-participant design with repeated measurements to increase power. In addition we use a computational modeling approach to trace which processes are influenced by the type of stimulus. We pursue two interlinked goals. First, we aimed at testing whether olfactory stimuli influence risky decision making. Specifically, we investigated whether the olfactory nature of the stimuli would affect participants' sensitivity to probabilities even when controlling for the subjective value of the outcomes. Given the inherently affect-rich nature of olfactory stimuli (e.g., Mohanty & Gottfried, 2013) and following the results from hypothetical studies on risky decision making with affect-rich stimuli, we expected that when choosing among olfactory outcomes, people would be less sensitive to probabilities than when choosing among monetary outcomes. In the context of CPT, we expected this to be reflected in a more strongly curved probability weighting function.

Second, existing studies that tested decision processes using real affect-rich outcomes yielded inconsistent results. To better understand the effect of real affect-rich outcomes requires a methodologically rigorous study. Odors are well suited for this task. Besides being inherently affect rich, odors can be studied in a laboratory setting (e.g., Coppin et al., 2014; Coppin, Delplanque, Porcherot, Cayeux, & Sander, 2012), and they lend themselves to consecutive presentations within a repeated-measurement design, minimizing carryover effects when using an appropriate interstimulus interval. Thus, using olfactory stimuli that are matched in value to monetary outcomes on an individual level makes it possible to use real nonmonetary outcomes that are genuinely affect rich and can be compared with a monetary control condition with the same perceived value.

3 | METHOD

To investigate these research questions, we conducted an experiment in which participants either lost money or encountered an unpleasant odor with a given probability. We used unpleasant odors because they elicit strong hedonic experiences (Schleidt, Neumann, & Morishita, 1988). To account for individual differences in affective reactions to unpleasant odors (Ferdenzi et al., 2013), following a literature review and a pilot study, we selected eight odors that most people have perceived as unpleasant (Chrea et al., 2009; Delplanque et al., 2008; Ferdenzi et al., 2011). In the main study, we asked participants to smell each of these odors and indicate how much they would be willing to pay to avoid smelling them again for 1 min. On the basis of these willingness-to-pay (WTP) judgments, we then selected for each person four odors for which their WTP judgments differed and constructed two sets of 42 pairs of gambles for each participant, one set involving odors and one set involving monetary losses (details on the selection of the odors and the construction of the gamble pairs are reported in Section 3.2). Gambles involving odors and monetary losses were matched so that the monetary losses equaled the amount of money a participant was willing to pay to avoid smelling the respective odor. At the end of the experiment, one decision was randomly selected for each participant and played out. The result determined the participant's outcome. Written consent was obtained from all participants before starting the experiment in accordance with the Declaration of Helsinki, and the study was approved by the ethical committees of the Psychology Department of the University of Geneva.

3.1 | Participants

Sixty students (52 women and eight men) from the University of Geneva participated in the study. To be able to detect a middle-sized effect (*d*) between 0.4 and 0.5 with a statistical power of 0.8 would require a sample size between 34 and 52 participants (Faul, Erdfelder, Buchner, & Lang, 2009). We decided to include 60 participants to ensure a large-enough power.

Participation was limited to nonsmokers who reported a normal sense of smell and who did not suffer from a respiratory infection. Mean age was 21.6 years (SD = 3.89). On average, the study took 50 min. Participants received a fixed payment of 10 Swiss francs (CHF) as compensation for participation. In addition, they could receive a bonus of up to 15 CHF depending on their decisions during the experiment (average amount paid was 24 CHF ≈ 25 USD; details on how payoffs were determined are reported in Section 3.3).

For the analysis of the choice data, we excluded 12 participants because they indicated fewer than three unique WTPs >0 for the odors in the first part of the experiment, which made it impossible to construct enough monetary gambles for these participants. The remaining 48 participants (seven men and 41 women) had an average age of 21.8 years. Another 16 participants indicated only three unique WTP judgments >0. For these, we restricted the analysis to the 21 gambles for which we could equate odors and monetary losses.

3.2 | Materials

3.2.1 | Odors

The eight odors used in the experiment were all rated as unpleasant but varied in their average ratings. Selected odors were pungent body odor, civet, old socks, cheese, sulfur and onions, feces, sweat, and cigarettes. All olfactory stimuli were injected into the reservoirs of cylindrical felt-tip pens (length 14 cm; inner diameter 1.3 cm). By using these “odor pens” (produced by Burghart, Germany), we avoided contaminating the environment with the odors.

3.2.2 | WTP judgments

To equate odors with monetary losses, participants rated how unpleasant they found each of the eight odors on a 7-point Likert scale of 1 (*do not like at all*) to 7 (*like very much*) and indicated how much they were willing to pay to avoid smelling it for 1 min continuously. Participants received the odor pens from the experimenter in a random order determined by the experimental software. To smell an odor, participants were asked to open the pen, hold it under their nose, take a breath, and close the pen again. Afterward, they were instructed to respond to questions about the odor in a computerized survey at their own speed and to tell the experimenter when they were ready to continue with the next odor. They were informed that they could ask to smell a fairly neutral odor (coffee) after each unpleasant odor, which they could smell for as long as they wanted.

To facilitate remembering each odor, the names were presented together with a picture (see also Figure 1) on a computer screen. To ensure that participants indicated their true WTP, they were informed that at the end of the study, one of their decisions in the study would be randomly selected to determine their final payoff (i.e., one of the WTP judgments or one of the gambles). If a WTP judgment was chosen, they would enter a Becker–DeGroot–Marschak (BDM) auction based on their WTP judgment (Becker, DeGroot, & Marschak, 1964).[2] We selected four odors for which participants responded with WTP

[2]A BDM auction is a method for ensuring that people provide their true WTP. If a BDM auction was played, a number from the range in which the WTP could lie was drawn (in our case, between 0 and 15 CHF). If the number was lower than or equal to the WTP, the participant paid this sum but did not smell the odor. If the number was larger than the WTP indicated, the participant had to smell the odor.

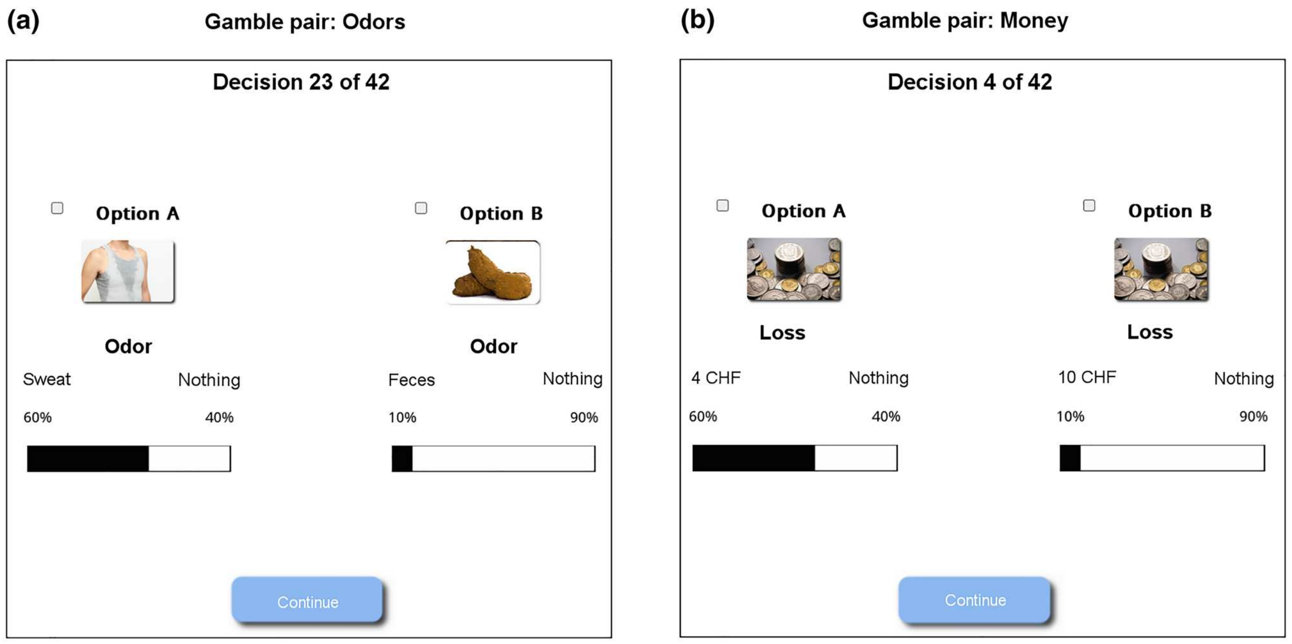

FIGURE 1 (a) A pair of gambles from the odor decisions. (b) A pair of gambles from the monetary decisions. Picture credits: “Poop”: stock photo, iStock.com/phanuchat; “Sweated man”: stock photo, iStock.com/deeepblue; “Spotlight on Modern Swiss Francs”: stock photo, iStock.com/ScottNodine [Colour figure can be viewed at wileyonlinelibrary.com]

judgments >0 and ≤15 CHF,[3] maximizing the range of WTP judgments for each participant.

3.2.3 | Gambles

On the basis of the WTP judgments for the four selected odors, we created two sets of 42 gamble pairs that involved a choice either between two unpleasant odors or between two monetary losses. In each gamble, the negative outcomes (monetary losses or unpleasant odors) would occur with a certain probability and no loss otherwise (see Figure 1 for an example). In the monetary gambles, the loss amounts were matched to the individual WTP judgments for the presented odors. This allowed a direct comparison between the choices in the odor sets and the monetary sets.

The 42 gamble pairs were constructed by creating all possible pairs of the four selected odors and a set of seven pairs of probabilities denoting the probability of a loss in the two gambles (.02 vs. .5; .1 vs. .6; .1 vs. .99; .2 vs. .4; .3 vs. .7; .3 vs. .9; .6 vs. .8). The more negative outcome (i.e., higher monetary loss or more negatively rated odor) was always presented with the lower probability, and the less negative outcome with the higher probability to avoid dominant options. We selected the pairs of probabilities so that (a) the probability of the worse loss would vary between very low (.02) and relatively high (.6) and that (b) the difference in the probability of losing between the two gambles covered a broad range of values (between .2 and .89). Table A1 provides an overview of all gamble pairs.

[3]The upper limit was set to 15 CHF to guarantee that a potential loss in the gamble selected to determine a participant's payoff would not exceed the bonus payment.

3.3 | Procedure

Participants performed the task in a well-ventilated room at the University of Geneva. First, they responded to questions regarding their sense of smell, age, and gender and how hungry they were and then continued to smell and rate the odors (WTP judgment phase). After the WTP judgment phase, participants continued with the decision problems. Equal numbers of participants started with either money or odor decisions. We varied between participants whether they first saw the money or the odor gambles. Within the odor and money block, we randomly determined the order of the gamble pairs for each participant. After 22 decisions, participants were encouraged to take a short break.

Before starting with the decision task, participants were informed that they would receive an extra 15 CHF for the study. At the end of the study, one of their decisions in the study (i.e., either one of the eight WTP judgments or one of the 84 pairwise gambles) was randomly selected and played to determine their payoff. If a monetary gamble was randomly selected, participants would receive the 15 CHF minus the amount they lost in the gamble. If an odor gamble was selected, they could choose whether they would like to smell the odor and receive the full 15 CHF or receive the 15 CHF minus the WTP judgment they had indicated for this odor. If a WTP rating was chosen, a BDM auction was played, and they either had to pay or had to smell depending on the outcome.

4 | RESULTS

4.1 | WTP judgments and selection of odors

Participants differed in which odors they found most unpleasant as well as in their WTP judgments. Ratings of the odors were highly correlated with WTP judgments (mean r = −.80, SD = 0.19). Figure 2a shows the average WTP judgments participants indicated for the eight odors. Figure 2b shows the average WTP judgments for the four selected odors ordered by their rank. The WTP judgments by rank represent the average monetary losses employed in the monetary gambles (see also Table A1).

4.2 | Choices

In the main analysis, we first analyzed whether people differed in the choices they made when outcomes were odors or monetary losses. For each individual, we calculated the proportion of choices of the option with the higher loss and the lower probability of losing (which in most cases was the more risky option) and the proportion of choices of the option with the higher expected value (for the odors based on their respective WTP judgments). On average, participants chose the risky option less frequently when deciding between odors (M = 0.56, SD = 0.25) than when deciding between monetary losses (M = 0.72, SD = 0.21). A Bayesian paired t test conducted in JASP (version 0.8.4; JASP Team, 2017) using the default prior (i.e., Cauchy with a 0.707 scale) provided strong evidence of a difference between the proportions. The obtained Bayes factor (BF_{10}) was 33.70, Cohen's d = 0.52. Similarly, participants were more likely to choose the option with the higher expected value when deciding between money gambles than between odor gambles (M_{money} = 0.77, SD = 0.16 vs. M_{odor} = 0.69, SD = 0.16, BF_{10} = 4.32, Cohen's d = 0.37). Both results are in line with the idea that participants in the affect-rich odor condition were less sensitive to differences in probabilities and tended to avoid the outcome with the higher loss.

One potential alternative explanation of the results could be that choices for the odor gambles were simply noisier and thus closer to the 50% choice share expected for random guessing. If this is the case, choice shares should be closer to 50% for all odor gambles compared with choice shares in the respective monetary gambles. That is, if in a monetary gamble 70% of participants chose the risky option, the choice share should be *lower* (i.e., closer to 50%) in the matched odor gamble—similar to what we would find on the average level. However, if in a monetary gamble only 30% of participants chose the risky option, the choice share should be *higher* (i.e., closer to 50%) in the matched odor gamble. And if the choice share in a monetary gamble was close to 50%, a *similar* choice share would be expected in the matched odor gamble. In contrast, if participants are indeed less sensitive to probabilities in odor gambles than in monetary gambles, choice shares in the odor gambles should be lower than in the monetary gambles in all cases. In sum, the *noise hypothesis* predicts an interaction between choice shares for the risky option in the monetary gambles and gamble type, whereas the *insensitivity hypothesis* predicts a main effect of gamble type and no interaction.

To test this, we conducted a logistic mixed model analysis using the mixed function in the afex package in R with a binomial link function and a likelihood ratio test (Singmann, Bolker, Westfall, & Aust, 2016) predicting participants' choices of the risky option (i.e., option with worse outcome) with gamble type (monetary vs. odor), the choice share of the risky option in the monetary gambles, and the interaction of the two variables as fixed effects. In addition, we included random intercepts for participants and gambles. As illustrated in Figure 3, the results show a clear main effect of gamble type, with participants being less likely to accept the risky gamble in odor gambles, $\chi^2(1)$ = 122.42, p < .001, but no interaction, $\chi^2(1)$ = 0.03, p = .867. Thus, the analyses provided no evidence for the noise hypothesis but are in line with the insensitivity hypothesis. Indeed, only in a single gamble was the proportion of participants choosing the option with the worse outcome lower for the monetary than for the odor gamble (see Table A1 for further details).

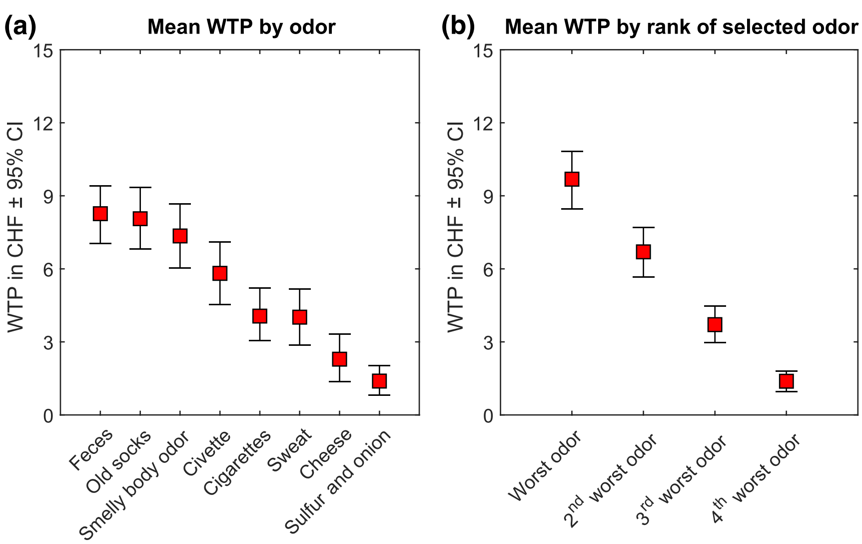

FIGURE 2 (a) The average willingness-to-pay (WTP) judgments for all eight odors. (b) The average WTP judgments of the selected odors ordered by their ranks. The figure contains data from all 60 participants. Error bars denote bootstrapped 95% confidence intervals (CIs) of the means [Colour figure can be viewed at wileyonlinelibrary.com]

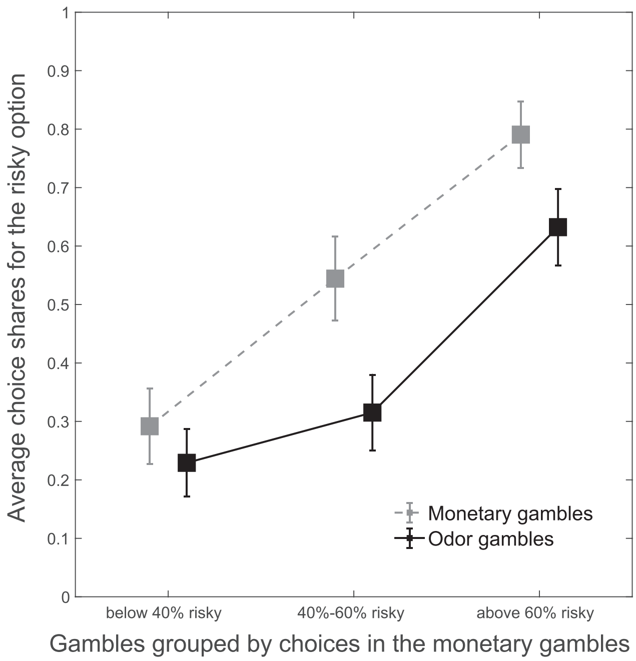

FIGURE 3 Gambles are grouped by choice shares for the risky option in the monetary gambles: ≤40% (*N* = 4 gambles), between 40% and 60% (*N* = 8 gambles), and ≥60% (*N* = 30 gambles). Error bars denote standard errors for proportions

4.3 | Participants' payoff

Participants' final payoffs in the experiment were determined by randomly selecting one of their decisions. The previous analysis showed that participants were more likely to choose odor gambles with less severe outcomes (i.e., a smaller loss/less unpleasant odor) but a higher probability of losing as compared with the matched monetary gambles. This apparent change in risk preferences should eventually also affect participants' payoffs in the study. Specifically, participants for whom an odor gamble was randomly selected as a payoff decision faced a higher probability of losing (i.e., having to smell the odor or incur a monetary loss) when the selected gamble was played than participants for whom a monetary gamble was selected.

To examine whether payoffs indeed differed, we considered the selected gamble for each participant and whether this gamble incurred a loss when it was played. For 35 of the 60 participants, an odor gamble was randomly selected as a payoff decision; for 18 participants, a monetary gamble was selected; and for seven participants, a WTP judgment was selected.[4] Of the 35 participants for whom an odor gamble was selected, 11 (31%) had to smell the odor or pay to avoid smelling it. In contrast, of the 18 participants for whom a monetary gamble was selected, only one (6%) lost money when the gamble was played. To test whether the selected odor gambles had a higher likelihood of losing than the selected monetary gambles, we conducted a directed Bayesian independent multinomial contingency test (JASP Team, 2017) with default priors. Results of this test showed that the loss likelihood was indeed higher for odor gambles than for monetary gambles (BF_{+0} = 5.51, directed test, *N* = 53).

Of the 11 participants who lost the selected odor gamble, seven decided to smell the odor and four decided to pay to avoid smelling the odor. These somewhat balanced choice shares suggest that overall, the WTP judgments accurately reflected participants' valuations.

4.4 | Modeling with CPT

To analyze whether the differences in the observed decisions stem from a change in the probability weighting function as suggested by the literature on hypothetical affect-rich gambles, we modeled the observed choices with CPT (for details, see Appendix B). Following previous research (Lejarraga et al., 2016; Pachur et al., 2017; Suter et al., 2016), we used the four-parameter version of CPT, with the alpha parameter defining the curvature of the utility function, the delta and gamma parameters defining the elevation and curvature of the probability weighting function, respectively, and the theta parameter capturing choice sensitivity.[5]

We implemented CPT in a hierarchical Bayesian framework, assuming for each parameter a joint distribution at the group level across both odor and monetary decisions and one additional parameter that coded the difference between odor and monetary decisions. We assigned each parameter a weakly informative uniform prior that constrained the range to realistic values. We estimated the model parameters in JAGS using three independent sampling chains with a length of 10,000 samples each. After a moderate amount of thinning, the chains mixed well and the sampling was efficient, as indicated by a visual inspection of the trace plots and the Gelman–Rubin statistic that was smaller than 1.01 for all parameters in the model.[6]

Figure 4 illustrates the posterior probability distributions for the four parameters at the group level. For the alpha, delta, and theta parameters, there was no credible (i.e., significant) difference between monetary and odor gambles. For the gamma parameter, a credible difference between the odor and money gambles was observed (BF_{10} = 27).

Figure 5 contrasts the estimated probability weighting functions for odor and monetary decisions across all participants. For the monetary decisions, the average probability weighting function is somewhat concave, suggesting that participants mostly overweighed the probabilities (see Figure 5a). For the odor decisions (Figure 5b), the average probability weighting function takes the usual inverse-S shape and is more strongly curved than the probability weighting function for the monetary gambles. Again, most participants showed relatively flat curves for a large range of probabilities, resulting in overweighting of low probabilities and suggesting a diminished sensitivity to differences in probabilities. However, individuals differed strongly in the elevation

[4] Odor gambles were more likely to be selected as payoff decisions than monetary gambles because participants with only three unique WTPs >0 played 42 odor decisions and only 21 monetary decisions.

[5] An additional analysis assuming θ = 1 led to the same conclusions.
[6] See online supplementary material for the JAGS code.

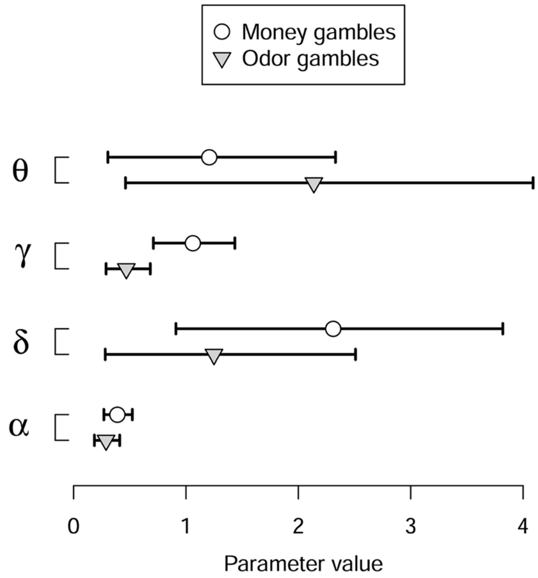

FIGURE 4 Posterior probability distributions of the cumulative prospect theory parameters on the group level for odor and monetary decisions. Symbols indicate the means of the posterior distribution; error bars indicate the 95% highest posterior density intervals

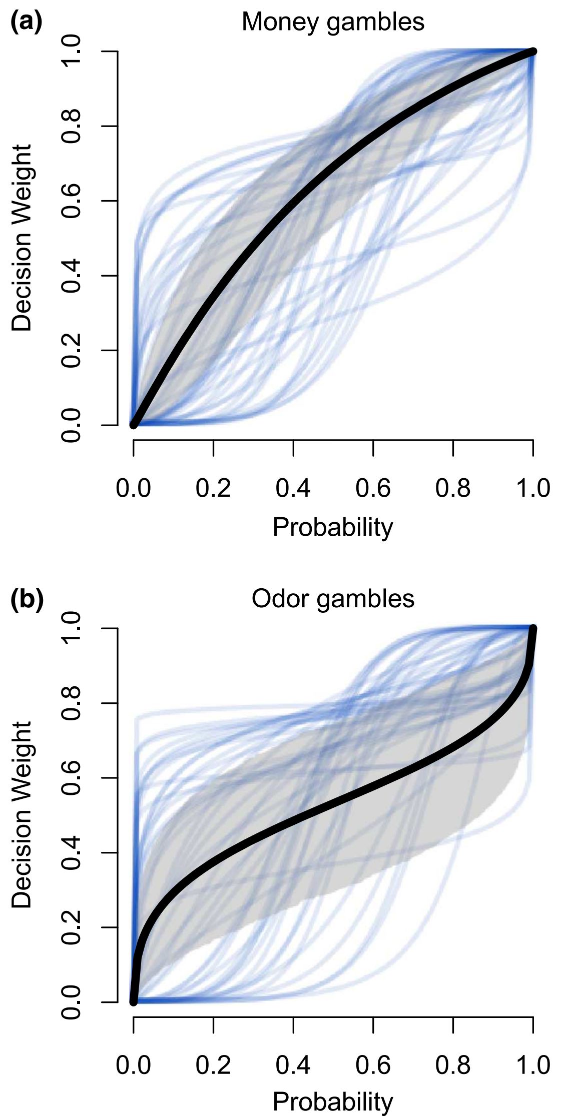

FIGURE 5 The estimated probability weighting functions for (a) decisions with monetary outcomes and (b) decisions with odor outcomes. Blue lines denote single participants; bold black lines denote the group mean; and the shaded grey areas denote 95% confidence intervals [Colour figure can be viewed at wileyonlinelibrary.com]

of the curves, with some participants underweighting low and overweighting high levels of probabilities.

5 | DISCUSSION

To reach a better understanding of how decision making changes when outcomes are affect rich, unpleasant, olfactory stimuli compared with monetary losses, we asked participants in a laboratory experiment to make a series of decisions involving real consequences (monetary losses or smelling unpleasant odors) that were matched in subjective value. On a behavioral level, participants were more likely to choose the more risky option in the monetary gambles than in the odor gambles, suggesting that participants were less sensitive to differences in probabilities with odor gambles. In line with these findings, modeling participants' choices with CPT using a Bayesian hierarchical approach showed a more strongly curved probability weighting function for odors than for monetary gambles. These results correspond to the literature on the changes in decision processes when outcomes are affect rich (e.g., Lejarraga et al., 2016; Pachur et al., 2014; Rottenstreich & Hsee, 2001; Suter et al., 2016). They suggest that in decisions involving affect-rich odors, participants' decision processes are less sensitive to probabilities. This result extends previous findings by Stancak et al. (2015) that unpleasant odors can increase loss aversion by showing that olfactory outcomes can also affect the subjective weighting or perception of probabilities. These insights are of direct importance for situations in which outcomes are olfactory. Furthermore, they support the initial findings by Ditto et al. (2006) showing a change in decision making when outcomes included an olfactory dimension. This suggests that odors will also affect risky decision making in situations in which odors are an integral and important feature of the outcomes, as in partner or food choice, for instance, when deciding whether food is still edible past its expiration date.

Moreover, our study provides clear evidence that affect-rich outcomes change sensitivity to probabilities even when outcomes are real and decisions consequential. By using choices with real consequences, we were able to investigate whether the choices participants made with money and odors differed in "quality" in the sense that they affected the likelihood of losing. Participants chose the gamble with the higher expected value less frequently in the odor gambles than in the monetary gambles. Furthermore, participants for whom the payout gamble was an odor gamble were more likely to incur a loss than participants for whom the payout gamble was a monetary gamble. Thus, participants may be less able to choose options that maximize their earnings when decision outcomes contain affect-rich outcomes such as unpleasant odors.

Although our results dovetail with those of previous studies using affect-rich outcomes (e.g., Rottenstreich & Hsee, 2001), there were some noteworthy differences from studies that used real affect-rich outcomes: Specifically, Krawczyk (2015) and Berns et al. (2007, 2008) did not find a decrease in sensitivity for the probabilities of affect-rich outcomes. Krawczyk used vouchers in his study and measured affect richness with how excited participants were about receiving the voucher. Possibly, the observed differences between affect-rich and affect-poor vouchers in this study reflected differences not only in affect but also in perceived utility.

For the differences from the studies by Berns et al. (2007, 2008), there are at least two possible explanations. First, Berns et al. investigated risky decisions using real affect-rich outcomes (i.e., electric shocks) but did not have a monetary control group and thus compared their findings with parameter estimates for gamma parameters within CPT reported in the literature (e.g., Abdellaoui, 2000; Tversky & Kahneman, 1992). In our study, we found differences in probability weighting, but the average probability weighting function estimated for the odor gambles actually resembled the parameter estimates reported in the above-mentioned studies more closely than the probability weighting function in the monetary gambles.[7] Thus, it is possible that in the studies by Berns et al., differences in probability weighting would have appeared if the same gambles had been presented with matched monetary outcomes. Second, in Berns et al.'s studies, participants received immediate feedback after each choice, whereas in our task, participants experienced the odor at the beginning but then did not receive feedback until the payout gamble selected at the end of the experiment. Perhaps differences in probability weighting diminish over time when participants experience real affect-rich outcomes repeatedly.

In addition, there are some limitations of our study. First, we had to exclude 20% of our participants because they did not perceive the odors as unpleasant enough to be willing to spend money to avoid smelling them again. Although we tried to include only participants with a normal sense of smell, we used a self-report measure. Thus, it is possible that these (or some of these) participants had a reduced sensitivity to odors that they were not aware of or not willing to disclose. Regarding the generalizability of our results, it could mean that the overall influence of odors on decisions is less strong than our results indicate. Second, we equated monetary losses and unpleasant odors based on participants' WTP judgments. This relies on the assumption that participants are able to accurately price smelling an unpleasant odor. Difficulties in setting a price for smelling an unpleasant odor might have driven the differences in choices, suggesting an alternative explanation for why odors or affect-rich outcomes in general lead to different choices than monetary outcomes (see also McGraw et al., 2010). What speaks against this explanation is that people's evaluations of unpleasant odors do not seem to change much over time and are not affected by familiarity (Delplanque et al., 2008; Delplanque, Coppin, Bloesch, Cayeux, & Sander, 2015), and participants' WTPs in our study were highly correlated with their odor ratings. Third, we used a combination of choice data and mathematical modeling to understand the changes in risky taking. However, to fully understand the cognitive processes underlying the observed changes in choices, we would need to use process-tracing methods, such as eye tracking or mouse tracking, which would allow us to investigate whether the observed differences in risky decision making can be traced to information processing, such as the attention allocated to outcomes (e.g., Lejarraga, Schulte-Mecklenbeck, Pachur, & Hertwig, 2019; Pachur, Schulte-Mecklenbeck, Murphy, & Hertwig, 2018). Finally, in our study, outcomes were odors, whereas in many decisions such as when evaluating food items, a new car, or clothes that still smell of the chemicals used for dying, odors will be just one attribute of the outcome. Here, it will be important in the future to test whether odors still affect the sensitivity to probabilities when other attributes also influence the overall utility of an option.

In conclusion, our study shows a qualitative change in decision processes for affect-rich olfactory outcomes, leading to a reduced sensitivity to probabilities. These results highlight the importance of taking olfactory stimulus dimensions into account when studying risky decision making. Furthermore, by using consequential decisions with real outcomes, the present study provides solid evidence that the affective intensity of outcomes is an important factor in risky decision making that should be taken into account to better understand the underlying cognitive processes.

[7]One reason for the relatively high gamma parameters we found in the monetary gambles in comparison with those reported in the literature could be our design that contained only four different outcomes. Thus, outcomes changed less between trials than probabilities. This could have increased the salience of the probabilities compared with other studies with more outcomes, which in turn could have influenced the probability weighting parameter (e.g., McGraw et al., 2010).

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CONFLICT OF INTERESTS

None.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX A

TABLE A1 Set of decisions

	Option A				Option B					
No.	Out A1	*p*A1 (%)	Out A2	*p*A2 (%)	Out B1	*p*B1 (%)	Out B2	*p*B2 (%)	Money	Odor
1	Worst	2	0	98	2nd worst	50	0	50	0.90	0.81
2	Worst	10	0	90	2nd worst	60	0	40	0.83	0.81
3	Worst	30	0	70	2nd worst	70	0	30	0.85	0.63
4	Worst	20	0	80	2nd worst	40	0	60	0.71	0.56
5	Worst	10	0	90	2nd worst	99	0	1	0.94	0.85
6	Worst	30	0	70	2nd worst	90	0	10	0.90	0.77
7	Worst	60	0	40	2nd worst	80	0	20	0.58	0.31
8	Worst	2	0	98	3rd worst	50	0	50	0.88	0.73
9	Worst	10	0	90	3rd worst	60	0	40	0.71	0.54
10	Worst	30	0	70	3rd worst	70	0	30	0.67	0.40
11	Worst	20	0	80	3rd worst	40	0	60	0.50	0.25
12	Worst	10	0	90	3rd worst	99	0	1	0.83	0.79
13	Worst	30	0	70	3rd worst	90	0	10	0.69	0.46
14	Worst	60	0	40	3rd worst	80	0	20	0.35	0.23
15	Worst	2	0	98	4th worst	50	0	50	0.72	0.50
16	Worst	10	0	90	4th worst	60	0	40	0.69	0.34
17	Worst	30	0	70	4th worst	70	0	30	0.47	0.25
18	Worst	20	0	80	4th worst	40	0	60	0.56	0.19
19	Worst	10	0	90	4th worst	99	0	1	0.81	0.53
20	Worst	30	0	70	4th worst	90	0	10	0.59	0.34
21	Worst	60	0	40	4th worst	80	0	20	0.22	0.16
22	2nd worst	2	0	98	3rd worst	50	0	50	0.92	0.83
23	2nd worst	10	0	90	3rd worst	60	0	40	0.85	0.75
24	2nd worst	30	0	70	3rd worst	70	0	30	0.79	0.60
25	2nd worst	20	0	80	3rd worst	40	0	60	0.69	0.52
26	2nd worst	10	0	90	3rd worst	99	0	1	0.90	0.81
27	2nd worst	30	0	70	3rd worst	90	0	10	0.77	0.69
28	2nd worst	60	0	40	3rd worst	80	0	20	0.52	0.46
29	2nd worst	2	0	98	4th worst	50	0	50	0.81	0.63
30	2nd worst	10	0	90	4th worst	60	0	40	0.75	0.47
31	2nd worst	30	0	70	4th worst	70	0	30	0.63	0.38
32	2nd worst	20	0	80	4th worst	40	0	60	0.53	0.19
33	2nd worst	10	0	90	4th worst	99	0	1	0.84	0.47
34	2nd worst	30	0	70	4th worst	90	0	10	0.59	0.53
35	2nd worst	60	0	40	4th worst	80	0	20	0.22	0.13
36	3rd worst	2	0	98	4th worst	50	0	50	0.78	0.78
37	3rd worst	10	0	90	4th worst	60	0	40	0.78	0.75

(Continues)

TABLE A1 (Continued)

	Option A				Option B					
No.	Out A1	pA1 (%)	Out A2	pA2 (%)	Out B1	pB1 (%)	Out B2	pB2 (%)	Money	Odor
38	3rd worst	30	0	70	4th worst	70	0	30	0.69	0.56
39	3rd worst	20	0	80	4th worst	40	0	60	0.72	0.50
40	3rd worst	10	0	90	4th worst	99	0	1	0.84	0.78
41	3rd worst	30	0	70	4th worst	90	0	10	0.84	0.72
42	3rd worst	60	0	40	4th worst	80	0	20	0.38	0.41

Note. The decision problems were created by presenting all combinations of the four outcomes with the set of seven probability pairs. The worse outcome always occurred with the lower probability. Out A1 and Out A2 denote the possible outcomes of Option A, and Out B1 and Out B2 the possible outcomes of Option B; *p*A1, *p*A2, *p*B1, and *p*B2 denote the probability with which the respective outcome would occur. In the odor decisions, Out A1 and Out B1 corresponded to smelling an odor; in the monetary decisions, Out A1 and Out B1 represented the monetary loss corresponding to the WTP of the participant for the respective odor. The ratings worst to fourth worst refer to the odors and monetary losses ordered based on participants' WTPs. Money and Odor present the proportions of participants choosing the option with the worse outcome for each gamble.

APPENDIX B: | COMPUTATIONAL MODELING WITH CUMULATIVE PROSPECT THEORY

Cumulative prospect theory (CPT) assumes that in two outcome lotteries with only one nonzero outcome, the subjective value V of an option A can be described as

$$V(A) = \sum_{i=1}^{n} v(x_i)w(p_i), \tag{B1}$$

where $v(x_i)$ reflects the value assigned to outcome x_i according to the value function of CPT:

$$v(x) = \begin{cases} x^{\alpha}, \text{if } x > 0 \\ -(-x)^{\alpha}, \text{if } x < 0 \end{cases} \tag{B2}$$

where α reflects the sensitivity to differences in outcomes. This results in a concave value function for gains and a convex value function for losses, with lower values of α yielding a stronger curvature. In the present study, we did not include a loss-aversion parameter because the choices we investigated contained only losses.

In Equation (B1), $w(p_i)$ denotes the probability weighting function that translates objective probabilities p_i into subjective decision weights according to Goldstein and Einhorn (1987):

$$w(p) = \frac{\delta p^{\gamma}}{\delta p^{\gamma} + (1-p)^{\gamma}}, \tag{B3}$$

where γ captures the sensitivity to differences in probabilities, with values <1 resulting in a more inverse-S-shaped curvature (indicating overweighting of small probabilities) and values >1 resulting in a more S-shaped curvature (indicating underweighting of small probabilities). The parameter δ reflects the elevation of the weighting function, with larger values of δ resulting in a higher elevation.

In a choice between two lotteries A and B, CPT predicts that the lottery with the larger V is preferred. We predicted the choice probability $p(A,B)$ of lottery A over B, with the softmax choice rule:

$$p(A,B) = \frac{e^{\theta \cdot V(A)}}{e^{\theta \cdot V(A)} + e^{\theta \cdot V(B)}}, \tag{B4}$$

where θ is a choice sensitivity parameter reflecting the sensitivity to differences in the valuations of $V(A)$ and $V(B)$, computed according to CPT.

Thus, our implementation of CPT involved four free parameters: α for the value function, γ and δ for the probability weighting function, and θ for the choice rule. In accordance with CPT's main assumptions, we restricted the range of the parameter values to theoretically plausible values (e.g., Scheibehenne & Pachur, 2015): $0 < \alpha \le 1$; $0 < \gamma \le 5$; $0 < \delta \le 5$; $0 < \theta \le 5$.